Tertiary Rocks

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Introduction

Following the period of crustal shortening and plutonism during the Late Cretaceous, a quiescent period ensued that lasted until about the early Miocene. Very little tectonic or magmatic activity has been documented for the Mojave Desert region during this quiescent period. The early to middle Miocene, however, was a period of intense volcanism and extensional faulting throughout much of the Mojave and Sonoran Desert regions. Volcanism in the East Mojave National Scenic Area (EMNSA) during the Tertiary, in part, reflects continental-scale retreat of calc-alkaline intermediate-composition magmatism from the southeast to the northwest along a narrow magmatic arc (Eaton, 1984). Eaton (1984) envisioned this region as a back-arc developed in a predominantly continental crustal environment. Much of the eastern part of the EMNSA represents a tectonic block that retained relative structural stability when extensional movement on low-angle normal faults resulted in significant rotation and disruption of supracrustal sequences in many of the mountain ranges to the north, southwest, and east of the EMNSA (Spencer, 1985; McCurry and Hensel, 1988; Reynolds and Nance, 1988; Burchfiel and Davis, 1988; Wilshire, 1988; Hileman and others, 1990). However, Miocene extensional deformation was described by Burchfiel and Davis (1988) in the Clark Mountain Range, as well as in the Mesquite Mountains and in the Kingston Range to the north and northwest of the EMNSA (see fig. 2). Sedimentary and tectonic deposits also accumulated in a Miocene extensional basin that underlies part of the Shadow Valley area (Reynolds and Nance, 1988; Wilshire, 1988). Multiple detachment faults exposed on Homer Mountain (Spencer, 1985), immediately east of the EMNSA, roughly coincide with the west edge of the north-trending Colorado River extensional corridor, which has been well documented in many of the reports cited above. The west edge probably lies east of the Piute Range, but the extensional corridor also may encompass the northern Piute Range and the Castle Mountains. The region immediately to the south of the EMNSA, including the Old Woman, Piute, Little Piute, and Ship Mountains (see fig. 2), underwent moderate extension during the Miocene (Hileman and others, 1990); the central Mojave, from Barstow to near Baker, may have been extended highly in the early Miocene (Glazner and others, 1989). Glazner and O'Neil (1989) determined a smooth eastward increase in initial whole-rock $^{87}Sr/^{86}Sr$ ratios for silicic volcanic rocks in the Mojave Desert region of southern California; they reported ratios for these types of rocks in the Castle Mountains that range from 0.70526 to 0.70990. Glazner and O'Neil (1989) interpreted the smoothness and lack of discontinuities in the eastward increase in initial whole-rock $^{87}Sr/^{86}Sr$ ratios to reflect the absence of any broad zones of pre-Tertiary rifting or major faulting. The increase in these ratios must be due to an eastward increase in the amount of crustal material incorporated into the magmas. Broad areas in the northern parts of the EMNSA also were subjected to moderate amounts of extension from the late Miocene into the Holocene in association with the development of pediment domes (see section below entitled "Development of Pediment Domes")

Overall basal stratigraphic sequences of both Tertiary rocks and Tertiary and Quaternary alluvial deposits are similar in the Piute Range, Castle Mountains, and the hills near Halloran Spring (fig. 2; Nielson and Nakata, 1993; Nielson and others, 1993; Reynolds, 1993). In each of these three areas, a Miocene sanidine- and sphene-bearing ash-flow tuff, the approximately 19–Ma Peach Springs Tuff of Young and Brennan (1974) (unit Tps, pl. 1), is present near the base of the Miocene section where it rests on arkosic sandstone and conglomerate that in turn rest unconformably on a basement of Proterozoic and Mesozoic metamorphic and igneous rocks. Volcanic rocks stratigraphically above the Peach Springs Tuff in the Piute Range include basalt to rhyodacite lava flows, volcaniclastic breccia, and air-fall tuff (Nielson and Nakata, 1993). In the Castle Mountains, andesitic-basaltic flows, minor basalt dikes, and volcanic breccias, all of which are interbedded with sedimentary rocks derived from andesitic-basaltic protoliths (Nielson and others, 1993), overlie the Peach Springs Tuff. Rhyolite plugs, flows, and sills, as well as rhyodacite ash-flow tuffs, all of which are associated with the gold deposits in the Castle Mountains, are younger than the intermediate-composition volcanic rocks. In the hills near Halloran Spring, fine-grained lacustrine rocks, which are in places interbedded with arkosic fanglomerate deposits, are present above an ash-flow tuff that is similar in age and lithology to the Peach Springs Tuff (Reynolds, 1993).

Van Winkle Mountain and Vicinity

The oldest Tertiary volcanic and sedimentary rocks in the region of the EMNSA are exposed in Van Winkle Mountain, northernmost Clipper Mountains (see fig. 2), and Old Dad Mountains (pl. 1). In Van Winkle Mountain, the sequence consists of tuff breccia, rhyodacite lava flows, and air-fall and ash-flow tuff that are capped conformably by olivine basalt flows (fig. 28*A*). These rock types are correlative with sequences of rock exposed to the west in the Bristol Mountains (see fig. 2) (Miller and others, 1985). The distinctive sanidine-bearing rhyolite tuff present near the top of this sequence has been correlated with the Peach Springs Tuff of Young and Brennan (1974) by Glazner and others (1986). Its presence at the top of the Tertiary sequence is in marked contrast to the presence of the Peach Springs Tuff near the base of the section in the northern part of the EMNSA. Thus, stratigraphy of Tertiary rocks and deposits comprises two geographically distinct sequences on the basis of the presence of the Peach Springs Tuff in two different places in the stratigraphic succession. This regionally extensive ash-flow tuff also has been used as a chronostratigraphic marker in many other mountain ranges in the eastern Mojave Desert of California and in western Arizona (Glazner and others, 1986). Published ages for the tuff range from 22 to 16 Ma. However, Nielson and others (1990) established an age of 18.5±0.2 Ma for the emplacement of the unit; they attributed the older reported ages to contamination by pre-Tertiary rocks, and the younger ages to alteration or incomplete argon extraction during the dating process. The Peach Springs Tuff is exposed in discontinous patches in the Piute Range, Castle Mountains, Mid Hills, New York Mountains, Bristol Mountains, Clipper Mountains, and on the east side of the Providence Mountains (pl. 1).

Hackberry Mountain, Woods Mountains, and Wild Horse Mesa

The Hackberry Mountain and Woods Mountains areas are underlain by volcanic and sedimentary rocks predominantly of middle Miocene age (pl. 1). These rocks rest unconformably on an erosional surface of pre-Tertiary crystalline basement that locally includes paleotopographic relief in excess of 300 m (Bonura, 1984). Flat-lying mesas in the western Woods Mountains and eastern Providence Mountains are capped by a prominent ash-flow tuff. The rocks that make up the tuff originally were informally termed the Hole-in-the-Wall tuff by McCurry (1985) but later were renamed the Wild Horse Mesa Tuff by McCurry (1988) (unit Tw, pl. 1; see also fig. 28*B*). The tuff represents approximately 80 km^3 of metaluminous to weakly peralkaline magma erupted at 15.8 Ma (McCurry, 1988). This eruption apparently produced a shallow trap-door caldera roughly 10 km in diameter centered in the eastern Woods Mountains (see section below entitled "Geophysics"). Resurgent doming and eruption of rhyolitic flows and tuff largely filled the caldera; one flow has been dated isotopically at 14.8 Ma. The final eruptions in the area of Woods Mountains were basalt, basaltic andesite, and basanite flows, one of which has a whole-rock K–Ar age of 10.3 Ma. Minor lacustrine and alluvial sedimentary rocks are intercalated in the upper part of the volcanic sequences exposed there, but some lacustrine deposits are also present stratigraphically below the Wild Horse Mesa Tuff and above the Peach Springs Tuff of Young and Brennan (1974). Large-magnitude aeromagnetic and gravity anomalies coincide with the caldera (see section below entitled "Geophysics"). On the basis of geophysical modeling, McCurry and Hensel (1988) suggested that the anomalies are probably due to a buried pluton. Rhyolite flows and domes, breccias, and tuffs on the east side of Hackberry Mountain and in the Vontrigger Hills have not been dated isotopically, and the Tertiary rocks in this area are less well understood than those in the western Woods Mountains. A lacustrine unit composed of limestone, dolomite, and minor sandstone at the top of the Tertiary sequence at Hackberry Mountain overlies the silicic volcanic rocks and contains vertebrate fossils of Barstovian to Calendonian age (McCurry, 1985). At Hackberry Mountain, the silicic rocks are made up of a high–K, trachyte-trachydacite-rhyolite association (McCurry, 1988). However, lacustrine rocks are also present near the base of the Tertiary sequence in the area of Wild Horse Mesa where their presence in areas of the thickest accumulations of the Wild Horse Mesa Tuff was used as evidence for the presence of a pretuff basin into which the tuff was deposited McCurry (1988).

Piute Range, Castle Mountains, Castle Peaks

The sequences of Cenozoic rocks exposed in the Piute Range are similar to those in the Castle Peaks area, and they have been correlated by Nielson and others (1987, 1993) and Nielson and Nakata (1993). The rocks in the Castle Mountains, although contemporaneous with rocks in the adjoining ranges, are dominated by rocks from a silicic volcanic center (fig. 29). These rocks thin rapidly to the east and west and apparently are not present in the Piute Range. Nielson and others (1987) divided the rocks of the Piute Range, which generally yield a smooth-sloped topography along much of the range (fig. 30), into two units. The lower unit consists of arkose and conglomerate that contain clasts derived from underlying pre-Tertiary basement in the Piute Range and possibly also from pre-Tertiary basement rocks exposed in the New York Mountains; basaltic andesite flows and breccias and some remnants of the Peach Springs Tuff of Young and Brennan (1974) are intercalated with the sedimentary rocks at the north end of the range. The upper unit consists of mafic lava flows and breccias, rhyolitic lava flows and tuffs, and interbedded alluvial sediments; a white tuff in the middle of the upper unit may be correlative with a similar tuff, which was first described by Miller and others (1986) in the general area of Castle Peaks but which is now known as the Wild Horse Mesa Tuff (Gusa and others, 1987).

The lower part of the exposed sequences of Tertiary rocks in the Castle Mountains comprises predominantly andesite underlain by what is probably the Peach Springs Tuff, thereby allowing correlation of these sequences with those in the Piute Range. Capps and Moore (1991), however, considered the basal tuff to be older than the Peach Springs Tuff, on the basis of the results of K–Ar ages of approximately 22 Ma that were obtained from the unit. The lower unit in the Castle Mountains has been folded into a broad, northeast-trending anticline (Turner and others, 1983; Turner, 1985). As much as 350 m of rhyolite flows, tuffs, and associated domes overlie the folded unit. The tuffs and rhyolites of this silicic volcanic center host most of the known mineralization in the Hart Mining District (see section below entitled “Tertiary Deposits”). The aggregate thickness of these silicic rocks apparently decreases rapidly to the south, west, and east, and they were not considered by Nielson and others (1987) to underlie the volcanic rocks of the Piute Range as Turner (1985) suggested. Geochronologic data reported by Turner (1985), Nielson and others (1987), Linder (1988), Ausburn (1988, 1991), and Capps and Moore (1991), are somewhat inconsistent but generally define a period of rhyolite, latite, and basalt volcanism that occurred from about 17 Ma to about 13 to 12 Ma in the Castle Mountains. The mineralization probably accompanied rhyolite-dome formation at about 15.5 Ma (Capps and Moore, 1991). An age of about 8 Ma (Nielson and others, 1987) on basalt from the Piute Range is the youngest age reported from the eastern part of the EMNSA.

Cima Volcanic Field

The volcanic rocks of the Cima volcanic field consist of more than 50 basalt cinder cones and numerous associated lava flows that overlie as much as 300 m of variably tilted Tertiary sedimentary rocks (pl. 1). The sedimentary materials were deposited nonconformably on, and are derived from, Cretaceous and older crystalline rocks (Wilshire and others, 1987). Eruptions of basalt in the area west of Cima Dome began as volcanism was waning elsewhere in the EMNSA. The majority of the flows associated with the Cima volcanic (basalt) field erupted between 7.6 Ma and the present, although an eruptive hiatus occurred between 3 and 1 Ma (Wilshire, 1988). The timing of the youngest flow has been estimated to be between 120,000 and 400 yr B.P. (H.G. Wilshire, written commun., 1991). All basalts in the field are alkalic, hypersthene- or nepheline-normative hawaiites or basanites (Wilshire, 1987). Study of Nd, Sr, and Pb isotopic compositions of hawaiites less than 1 Ma in age from the Cima volcanic field suggested that they were derived from a mantle source (Farmer and others, 1991). Wilshire and others (1988) discussed the possible origins of various types of xenoliths found in the Cima volcanic field.

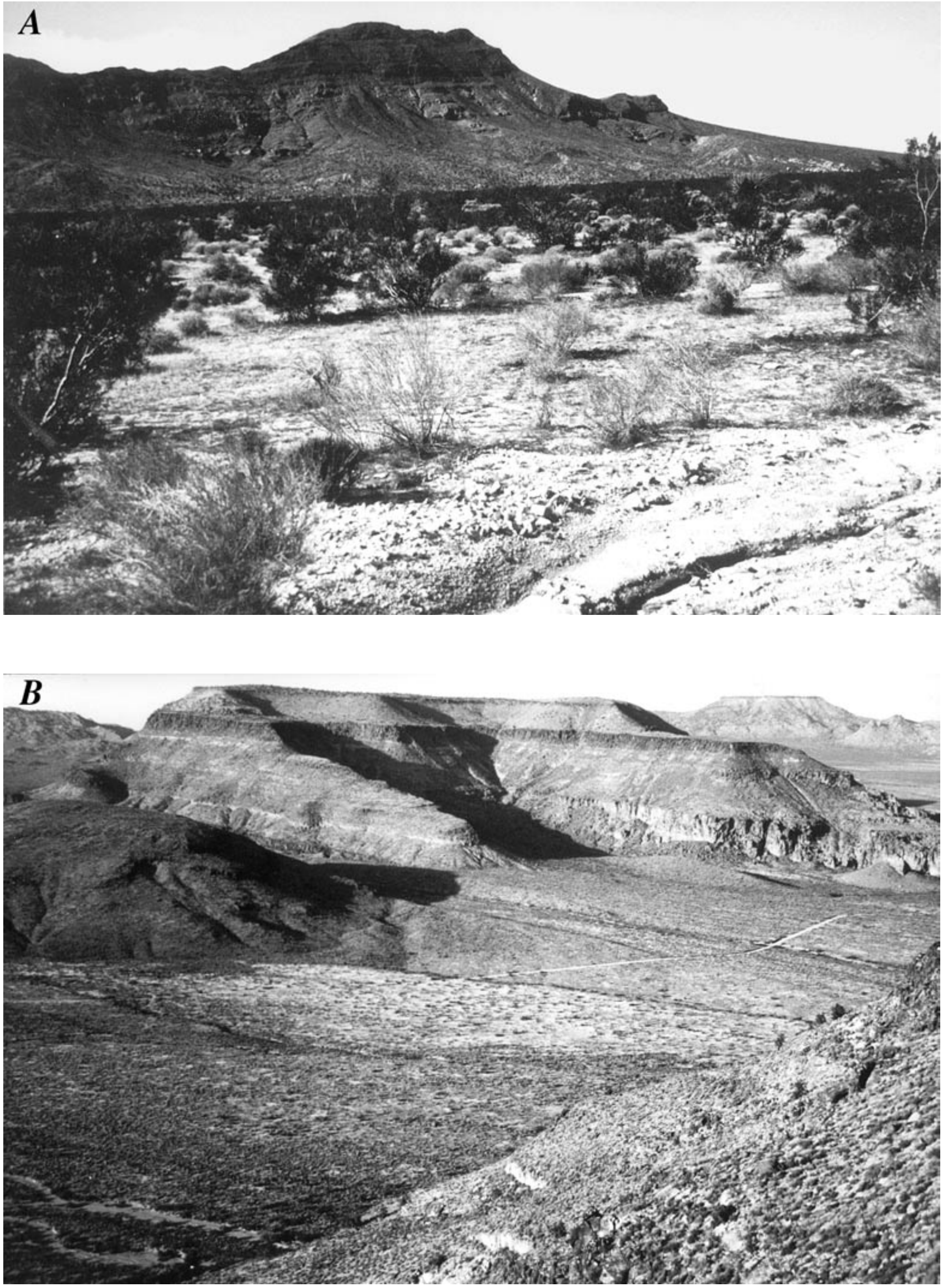

Figure 28. Tertiary volcanic sequences in East Mojave National Scenic Area, Calif. *A*, Volcanic sequence at Van Winkle Mountain (fig. 2). Light-colored tuffaceous rocks are capped by dark basalt lava flows. *B*, Wild Horse Mesa Tuff of McCurry (1988) in spectacular Wild Horse Mesa (fig. 2) with steep, eroded flanks. Hole-in-the-Wall lies to right of, and just beyond, mesa in upper right part of view.

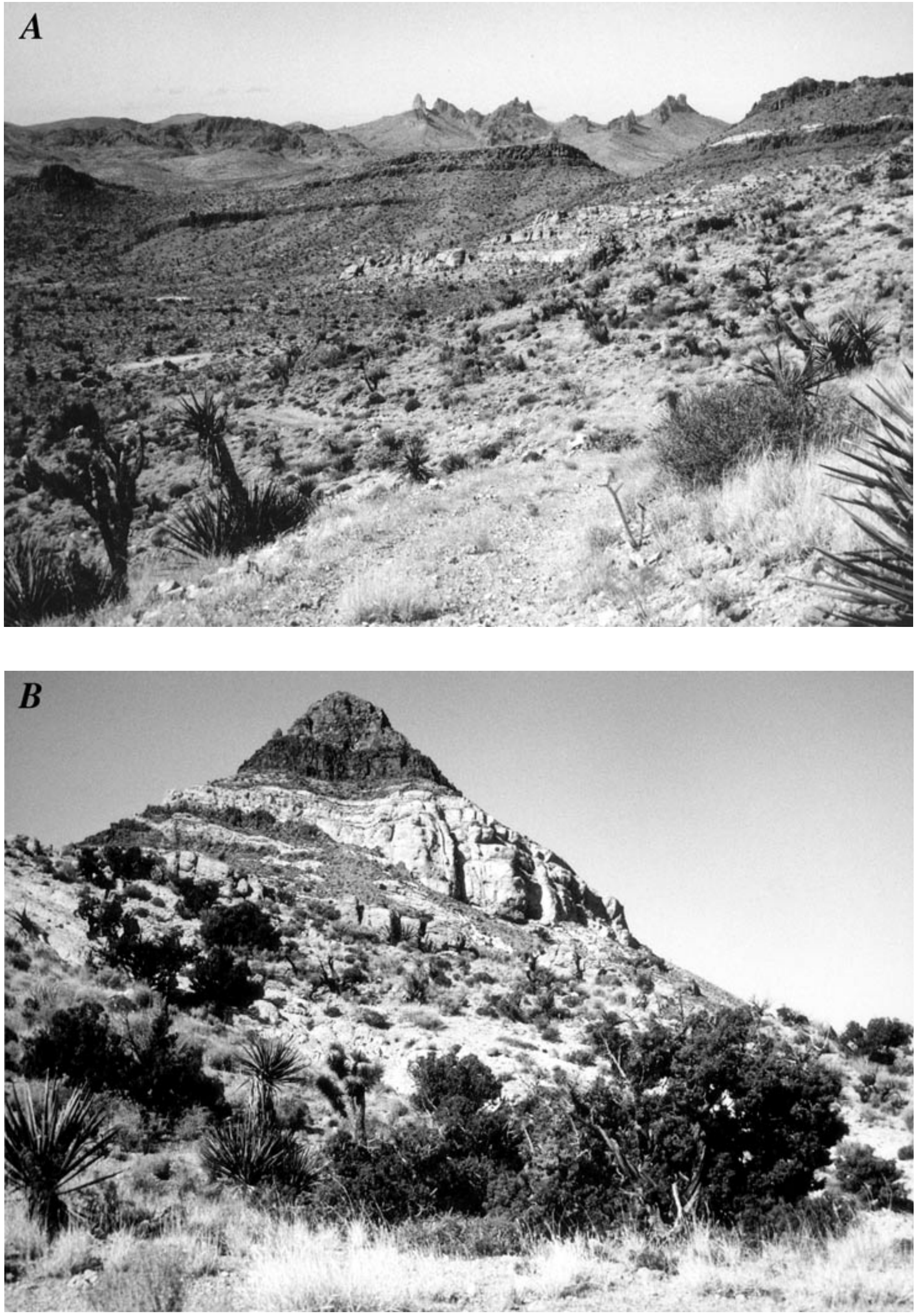

Figure 29. Silicic volcanic rocks in Castle Mountains (fig. 2), near northeast margin of East Mojave National Scenic Area, Calif. *A*, In foreground, light-colored ash-flow tuff approximately 13–12 Ma; slightly older rhyolitic rocks at Castle Peaks on skyline. *B*, Prominent peak capped by ash-flow tuff and underlain by dark basal vitrophere just below triangular top of peak. Sample collected at top of peak yielded 14 Ma date.

Figure 30. Smooth, rounded slopes of east-dipping Miocene andesite in Piute Range, East Mojave National Scenic Area, Calif.